Journal of Forestry Research (2011) 22(3): 399–402
DOI 10.1007/s11676-011-0114-7

ORIGINAL PAPER

Variations in bark thickness and sapwood density of *Calophyllum inophyllum* provenances in Australia and in Sri Lanka

Subhash Hathurusingha • Nanjappa Ashwath

Received: 2010-07-28; Accepted: 2010-08-26

Abstract: Sapwood density and bark thickness of *Calophyllum inophyllum* L. (a multipurpose durable timber species) were studied in various locations in Northern Australia and in Sri Lanka. Measurements were taken non-destructively by using core sampling and bark gauge. From each provenance, 4–15 mature trees having girth at breast height over bark (GBHOB) at 100–150 cm were selected on the basis of the population size. Significant (p<0.05) hemispheric and provenance variations in bark thickness were found. Variations in the bark thickness are influenced by environmental variables. Variations in sapwood density were less pronounced compared to that of bark thickness. Variations in sapwood density are likely to be governed by genotypic variations.

Keywords: bark thickness; *Calophyllum inophyllum*; provenance variations; sapwood density

Introduction

Calophyllum inophyllum L. (Clusiaceae), commonly known as Alexandrian laurel, beauty leaf or Domba (in Sri Lanka), is a medium to large evergreen tree that grows up to 20 m in height with a broad spreading crown of irregular branches. It generally is grown above the high tide mark of coastal areas (Friday et al. 2006). *C. inophyllum* is a good general-purpose timber (Maiden 1975). The wood is often fine textured, and the grain is more interlocked. The density is 560–900 kg·m^{-3} at 15% moisture content (Timber Species Notes, DPI Queensland 2007). The sapwood, yellow-brown with a pink tinge, is well defined from the heartwood that is deep red, red-brown, pink-brown or orange-brown. Vessels are large to medium size, solitary and arranged in oblique flares. Vessel lines are very prominent on dressed surfaces and darker than surrounding tissue. The timber is generally slightly heavier, stronger and more durable than that of other *Calophyllum* species.

Mechanical handling of *Calophyllum* wood is categorized as easy (MTC wood wizard 2006). In several regions, the wood is much sought after for masts, spars, bridgework and scaffolding due to the tall, slender form of the poles. Because the wood is close grained and durable, it is commonly used for boat building and railway sleepers. Rich reddish-brown appearance makes it excellent for veneer, plywood and cabinet making. The wood is also used for light construction, flooring, moulding, joinery, wooden pallets, diving boards, cartwheels and axles, musical instruments and blowpipes (Little and Skolmen 1989).

The bark of *C. inophyllum* is shallowly longitudinally fissured, pale grey and fawn, inner bark usually thick, soft, fibrous and laminated, pink to red, darkening to brownish on exposure (Lemmens 2005). *Calophyllum* bark is an Indo-Chinese medicine for orchitis (Dweck 2002) and acts as an antiseptic and disinfectant. Some scientists found a cytotoxin (calocoumarin A) that can be used to treat skin cancer from bark extracts of *C. inophyllum* (Itoigawa et al. 2006). Bark thickness may be correlated to secretions (Hedge et al. 1998).

C. inophyllum shows wide distribution, ranged from northern Australia and extending throughout Southeast Asia and southern India (Hathurusingha and Ashwath 2007). Geographic variation may induce variations in wood properties. Wood properties vary within trees, between trees, between stands and regions (Stahl 1998). Bark thickness is also greatly dependent on environmental conditions. Bark thickness can be used as a useful raw parameter for selecting suitable provenances for cultivation as a medicinal plant and likewise sapwood density can be used to identify suitable cultivars for commercial timber plantations. However, there is a significant lack of information on the provenance related variations in wood properties of *C. inophyllum*. This study was conducted to explore .the variations in bark thickness and sapwood density of *C. inophyllum* provenances in Australia and in Sri Lanka.

The online version is available at http://www.springerlink.com

Subhash Hathurusingha (✉) • Nanjappa Ashwath
Centre for Plant and Water Science, CQ University, Bruce highway, Rockhampton 4702, Australia.
E-mail: s.hathurusingha@cqu.edu.au. Tel: +61749232110.

Responsible editor: Yu Lei

Materials and methods

Conditions of provenances

The study was conducted in ten provenances (Table 1): six in northern Australia (Townsville, Yeppoon, Cardwell, Bowen, Mackay and Darwin) and four in Sri Lanka (Anuradhapura, Colombo, Kurunegala and Matara). The selected provenances from different areas are distinct in terms of climate, topography and soil conditions. The distance between each provenance is at least 100 km.

Sampling

Sampling was greatly restrained by the small size of the stands in each provenance. The number of sites/provenance varied from 2 to 4 due to the availability. From each site (2–5) morphologically superior (free from diseases and defects and appear to have a healthy form) mature trees were selected with girth at breast height over bark (GBHOB ranging from 100–120 cm). This step was taken to standardize the sample in the comparison of field data and to address the age effect as an effort.

Table 1. *Calophyllum inophyllum* L. provenances in Australia and in Sri Lanka

Provenance	Coordinates	Altitude from MSL (m)	Mean annual rainfall (mm)	Mean annual temperature Max/Min(ºC)	Soils
Provenances in Australia					
1. Townsville	19°13'0"S, 146°48'0"E	3.5	1124.8	28.9/19.8	Mungol and submature back earths
2. Yeppoon	23°7'42"S, 150°44'34"E	5	870.1	25.9/18.5	Rundle, Shallow stony browns, clay loams and sandy clay loams.
3. Cardwell	18°16'0"S, 146°1'60"E	5	2125.3	28.7/18.9	Solonetz, Planosols, calcareous dune sands
4. Bowen	20°1'0"S, 148°13'60"E	3	864	28.6/19.7	Mottled subsoil dune sand
5. Mackay	21°08'36"S, 149°11' 12"E	3	1522.6	27.0/17.7	Andergrove calcareous variant and sandy loams
6. Darwin	12°27'0"S, 130°50'0"E	5	1712.9	32.0/23.2	Regosols, Leptosols and Planosols
Provenances in Sri Lanka					
7. Anuradhapura	08°20'60"N, 80°22'60"E	75	1094	32.1/23.3	Reddish brown earths & immature brown loams
8. Colombo	6°54'0"N, 79°50'0"E	59	2500	30.6/24.1	Red-yellow podzolic with soft and hard laterite, dark heavy clay soils.
9. Kurunegala	7°45'0"N, 80°15'0"E	55	1500	31.7/22.8	Red yellow podzolic soils with strongly mottled subsoil, low humic gley soils, regosols on red and yellow sands
10. Matara	5°56'55"N, 80°32'34"E	40	2150	29.3/24.1	Alluvial soils, Red-yellow podzolic with soft and hard laterite

Measurements of bark thickness and sapwood density

Bark thickness of three trees was measured at each selected site using a bark gauge. Two perpendicular measurements were taken for each tree at 1.3 m height. To measure sapwood density non-destructively, two core samples of sapwood (windward and leeward) were taken from three trees at each selected sites using an increment borer (i.d. 5.15 mm). Samples were dried in an oven for 48 hours at 104°C. Then the length and dry weight of each piece were recorded (Chave 2006a).

Sapwood densities were obtained from the following equation.

$$\rho_s = \frac{W_d \times 4}{\pi d^2 l} \tag{1}$$

where, W_d is the dry weight of the core sample, ρ_s is the sapwood density, d and l were diameter and length of core samples.

Soil analysis

Two sites from each provenance were selected for soil analysis. At each site three morphologically superior trees (from those selected for other parameters) were selected. Three cores were taken at each tree (3 m radius from the tree) by using 2.5 m auger.

Cores of 0–30 cm in the same site were mixed to form a representative composite of the site. Samples were collected in linen bags and brought to the laboratory and transferred to oven set up at 40°C. In each sample organic debris and stones was sieved by 2 mm sieve. One sample (750 g) from each site was analysed for nitrogen, potassium, phosphorus, total carbon, pH and conductivity by ISO 10390, ISO 10694, ISO 11047, ISO 13878 and TPS ion meters.

Analysis of data

After testing the normality and homogeneity of error variances, differences among provenance means were tested by Tukey simultaneous test using the General Linear Model (GLM) of ANOVA in MINITAB ver. 14.1. Pearson correlation coefficients were calculated between soil and climatic variables, and bark thickness and wood density by the above software.

Results and discussion

Results indicated marked variations in wood density and bark thickness among *C. inophyllum* provenances from Australia and Sri Lanka. Significant ($p > 0.05$) hemispheric variations in bark thickness were found between *C. inophyllum* stands from Austra-

lia and Sri Lanka (Table 2). *Calophyllum* trees in Australia are mostly found in coastal areas and exposed to dry salty air. In contrast, *Calophyllum* trees in Sri Lanka occur in humid inland areas with different soil types (Personal Observations 2008).

Table 2. Provenance variations in bark thickness

Provenance	n	Bark thickness (mm)
Townsville	10	15.4c
Yeppoon	4*	11.3ab
Cardwell	14	12.4b
Bowen	8	11.9b
Mackay	4*	10.4ab
Darwin	14	12.2b
Anuradhapura	6*	8.3a
Colombo	15	8.8a
Kurunegala	6*	8.9a
Matara	10	9.1a

The means that are not followed by the same letter are significantly different (at 0.05 level of probability) as determined by the Tukey simultaneous test. "*" is the number of available trees, "n" is the number of individuals.

Thicker barks found in Australian *C. inophyllum* trees is may be due to the exposure to salty winds and low relative humidity. Thicker woody barks may have been developed to prevent dehydration.

C. inophyllum provenances demonstrated a range of sapwood densities (494–636 kg·m^{-3}). Sapwood density of *C. inophyllum* had a relatively less pronounced hemispheric variation (Fig. 1). Trees from Yeppoon, Mackay and Kurunelaga had lower but similar sapwood densities (494–510 kg·m^{-3}). Similar sapwood densities were also observed among the trees from Anuraadhapura and Matara (539 kg·m^{-3}and 541 kg·m^{-3}), and Townsville, Cardwell, Bowen and Darwin (574–590 kg·m^{-3}). Highest mean sapwood density value (636 kg·m^{-3}) was observed among those trees from Colombo. It was significantly different (p < 0.05) from the rest of the provenances. *Calophyllum* stands in all selected provenances except Colombo were growing on relatively lose soils. Most of the trees sampled in Colombo were growing on black heavy clay or compact soils which restrict their root respiration. This induces slow growth, which leads to dense wood formation (Slik et al. 2010).

Bark thickness in *C. inophyllum* was found to be strongly influenced by environmental variables. Negative correlations were found between bark thickness and climatic parameters (Table 4). Highest coefficient (r= -0.72) was found between bark thickness and altitude. Possible cause for the marked difference between bark thickness of Australian provenances and Sri Lankan provenances as mentioned earlier could be the difference in relative humidity (RH) and can be further supported by significant correlations between bark thickness and RH.

Among climatic variables, mean of annual maximum temperature (r= -0.31) and mean of annual rainfall (r= -0.32) have shown the least correlation with bark thickness.

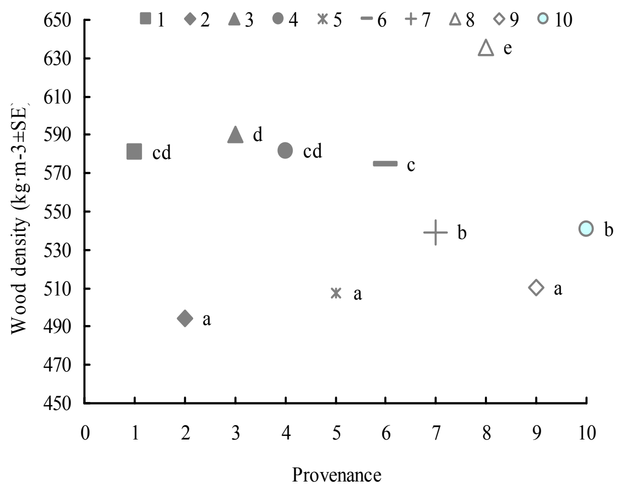

Fig. 1 Variation in the wood density of *Calophyllum inophyllum* provenances in Australia and Sri Lanka.

Means that are not followed by the same letter are significantly different (at 0.05 level of probability). 1. Townsville, 2. Yeppoon, 3. Cardwell, 4. Bowen, 5. Mackay, 6. Darwin in Australia; 7. Anuradhapura, 8. Colombo, 9. Kurunegala, 10. Matara in Sri Lanka

Wood densities of *C. inophyllum* were not found to correlate with climatic variables (Table 3). Chave et al. (2006b) and Moser et al. (2008) reported that wood density correlates negatively or neutrally with elevation. Numbers of other authors reported that there were no correlations between geo-climatic variables and bark thickness (Warrall 1974; Wright 1987; Bergin et al. 2007).

Bark thickness of *C. inophyllum* was also found to strongly correlate with soil parameters (Table 4). Significant positive correlations were found between bark thickness and soil nitrogen (r= 0.77), and potassium levels (r= 0.59). Bark thickness was negatively correlated to total carbon (r= -0.49) and conductivity (r= -0.55). However, bark thickness was not significantly influenced by either soil phosphorus level (r= 0.17) or soil pH values (r= 0.03).

In contrast, wood density was not significantly correlated to any of the measured soil parameters (Table 4). Only visible negative correlation was found between wood density and total carbon (r= -0.24). It may be due to the promotion of carbohydrate and cellulose synthesis as apposed to lignin synthesis in carbon rich soils. Carbon rich soils are generally associated with wet environments and under those conditions plants usually are less likely to consume energy in water conservation.

In conclusion, sap wood density of *C. inophyllum* was not found to be regulated by environmental parameters such as geo-climatic factors or soil parameters. Warrall (1974) suggested that heritability of wood characters can be very high. This demonstrates that provenance variations in sapwood density are mainly governed by genotypic variations. In contrast, provenance variations in bark thickness are strongly regulated by environmental variables.

Table 3. Correlations between bark thickness and wood density, and climatic parameters of selected provenances

Wood Character	Mean Annual Maximum Temperature (°C)	Mean Annual Minimum Temperature (°C)	Altitude (m)	Mean Annual Rainfall (mm)	Mean Annual Relative Humidity (%)
Bark Thickness (mm)	-0.31(0.05)	-0.57 (<0.0001)	-0.72 (<0.0001)	-0.32 (<0.0001)	-0.57 (<0.001)
Wood density ($kg{\cdot}m^{-3}$)	0.12 (0.25)	0.06 (0.52)	0.001 (0.98)	-0.14 (0.16)	0.02 (0.84)

Values are Pearson product-moment correlation coefficient, *r*. *p*-values are given in parentheses

Table 4. Correlations between bark thickness and wood density, and soil parameters of selected provenances

Wood Character	Soil Parameters					
	N	P	K	Total C	pH	Conductivity ($\mu S{\cdot}cm^{-1}$)
Bark Thickness (mm)	0.77 (<0.0001)	0.17 (0.13)	0.59 (<0.0001)	-0.49 (<0.0001)	0.03 (0.2)	-0.55 (<0.0001)
Wood density ($kg{\cdot}m^{-3}$)	0.03 (0.70)	-0.08 (0.41)	-0.08 (0.43)	-0.24 (0.07)	0.18 (0.07)	-0.17 (0.09)

Values are Pearson product-moment correlation coefficient *r*. *p*-values are given in parentheses. Soil nutrient values were taken as percentage dry weight.

Conclusions

Calophyllum inophyllum provenances demonstrated marked hemispheric variations in bark thickness. Variations in bark thickness were influenced by environmental variables. There were significant provenance variations in sapwood density. But those variations were not influenced by environmental variables, suggesting that it could be governed by genotypic variations.

Reference

Bergin DO, Kimberley MO, Low CB. 2007. Provenance variation in *Podocarpus totara* (D. Don): Growth, tree form and wood density on a coastal site in the north of the natural range, New Zealand. *Forest Ecology and Management*, **255**: 1367–1378.

Chave J, Muller-Landau HC, Baker TR, Easdale TA, Steege HT, Webb CO. 2006a. Regional and phylogenetic variation of wood density across 2456 Neotropical tree species. *Ecological Applications*, 16: 2356–2367.

Chave J. 2006b. *Measuring wood density for tropical forest trees field manual,* Lab. Evolution et Diversité Biologique Université Paul Sabatier, 31000 Toulouse, France.

Dweck AC, Meadows T. 2002. Tamunu (*Calophyllum inophyllum*)-the African, Asian, Polynesian and Pacific Panacea. *International Journal of Cosmetic Science*, **24**: 1–8.

Friday JB, Okano D. 2006. *Calophyllum inophyllum* (kamani) Species Profiles for Pacific Island Agroforestry, Traditional Tree Initiative, Hawaii. www.traditionaltree.org, accessed 17/09/2007.

Hathurusingha HMSD, Ashwath N. 2007. *Beauty Leaf, a Tree with Great Economic Potential,* 12th International Forestry Symposium. Kalutara, Sri Lanka, 12p.

Hedge V, Chandran MDS, Gadgil M. 1998. Variation in bark thickness in a tropical forest community of Western Ghats in India. *Functional Ecology*, **12**: 313–318.

ISO 10390. 1994. Soil Quality – Determination of pH. International Organization for Standardization. Geneva, Switzerland. 5 p. (available at www.iso.ch)

ISO 10694. 1995. Soil Quality – Determination of organic and total carbon after dry combustion (elementary analysis). International Organization for Standardization. Geneva, Switzerland. 7p. (available at www.iso.ch)

ISO 11047. 1998. Soil Quality – Flame and electrothermal atomic absorption spectrometric methods. International Organization for Standardization. Geneva, Switzerland. 6 p. (available at www.iso.ch)

ISO 13878. 1998. Soil Quality – Determination of total nitrogen content by dry combustion ("elemental analysis"). International Organization for Standardization. Geneva, Switzerland. 5p. (available at www.iso.ch)

Lemmens RHMJ. 2005. *Calophyllum inophyllum* L. In: Louppe, D. (eds), Prota 7: Timbers/Bois d'œuvre. [CD-Rom]. PROTA, Wageningen, Netherlands.

Little EL, Skolmen RG. 1989. Common forest trees of Hawaii (native and introduced), USDA Agriculture Handbook 679, Washington.

Maiden JH. 1975. *The Useful Plants of Australia*. Melbourne, Australia: Compendium Pty Ltd., 215, 284, 390 pp.

Masataka I, Chihiro I, Hugh TWT, Masashi K, Harukuni T, Hoyoku N, Hiroshi F. 2001. Cancer chemopreventive agents, 4-phenylcoumarins from *Calophyllum inophyllum* . *Cancer Letters*, **169**: 15–19.

Moser G, Röderstein M, Soethe N, Hertel D, Leuschner C. 2008. Altitudinal changes in stand structure and biomass allocation of tropical mountain forests in relation to microclimate and soil chemistry. *Ecological Studies*, **198**: 229–242.

MTC wood wizard, an online database; http://woodwizard.mtc.com.my:8888 / (accessed 17/08/2006).

Slik JWF, Aiba SI, Brearley FQ, Cannon CH, Forshed O, et al. 2010. Environmental correlates of tree biomass, basal area, wood specific gravity and stem density gradients in Borneo's tropical forests, *Global Ecology and Biogeography*, **19**(1): 50–60.

Stahl EG. 1998. Changes in wood and stem properties of *Pinus sylvestris* caused by provenance transfer. *Silva Fennica,* **32**(2): 163–172.

Timber species notes index, Hardwoods advice. 2007. Department of Primary Industries and Fisheries. Queensland, Australia.

Warrall J. 1974. Provenance and clonal variation in phenology and wood properties of Norway spruce. PhD thesis. Faculty of the Graduate School, Yale University, USA.

Wright JA. 1987. Provenance variation in wood characteristics of Pinus caribaea Morelet and Pinus oocarpa Schiede. PhD thesis. University of Oxford, England.